



DECLARATION

I, Jun OKAMOTO, residing at 2023, Takao-machi, Hachioji-shi, Tokyo, Japan, do hereby certify that I am conversant with the English and Japanese languages and am a competent translator thereof. I further certify that to the best of my knowledge and belief the attached English translation is a true and correct translation made by me of U.S. Patent Application No. 10/727,044 filed on December 4, 2003.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 30th day of March, 2004

A handwritten signature in black ink, appearing to read "Jun Okamoto".

Jun OKAMOTO

Description

Composite Material and Processing Method Using the Material

Cross Reference to Related Application

The present application is filed under 35 U.S.C. §111(a), and claims benefit, pursuant to 35 U.S.C. §119(e)(1), of the filing date of Provisional Application No. 60/432,247 filed 11 December, 2002 pursuant to 35 U.S.C. §111(b).

Technical Field of the Invention

The present invention relates to a composite material and a processing method using the material. More particularly, the present invention relates to a composite material containing abrasive grains employed for grinding, polishing, or cutting, such as a wheel, a blade, a brazed cutting tool, or a throw-away tip; and to a processing method employing the composite material. The present invention also relates to an abrasive composite material employed for precision grinding or precision polishing of an electronic part such as a semiconductor wafer, an interlayer insulating film, or a wiring material by means of the fixed abrasive method; to a grinding material or polishing material containing the composite material; and to a method for processing an electronic part such as a semiconductor wafer, the method employing the composite material.

Background Art

In recent years, keeping pace with the advancement in high-performance semiconductor devices, electronic circuits have attained increased degree of integration and miniaturization. Successful formation of a sophisticated wiring structure on the surface of a semiconductor substrate calls for planarization of the imaging surface; i.e., the semiconductor substrate surface. This process is critical for alleviating the miniaturization limit of circuit patterns formed by photolithography, or stated differently, the shallow focal depth.

In a generally employed method for attaining semiconductor substrate planarization by means of chemical mechanical polishing, a substrate supported by a carrier is rotated while a slurry prepared by dispersing abrasive grains in an abrasive liquid is supplied to a polishing pad, whereby the substrate is polished. For example, a slurry for polishing an insulating film is prepared by dispersing, in an abrasive liquid, silicon dioxide (see, for example, Japanese Patent Application Laid-Open (*kokai*) No. 2001-26771 (USP 6248144)), cerium oxide (see, for example, Japanese Patent Application Laid-Open (*kokai*) No. 2001-179610), or a similar substance. Such a method, which employs a relatively soft polishing pad in order to prevent damage to a substrate, involves a problem in terms of low polishing speed attributed to the abrasive grains not being held on the polishing pad. In the case where a circuit-pattern-printed substrate is

polished, the polishing speed varies in accordance with the distance between circuit wiring patterns, leading to occurrence of non-uniform polishing, such as dishing or thinning. In addition, such a method involves a problem in terms of, for example, treatment of used abrasive grains.

In order to solve problems associated with the aforementioned semiconductor substrate planarization method, there has been proposed another method in which a substrate is pressed onto a rotating disk onto which abrasive grains are fixed, and the substrate is polished while the disk is rotated or slid (see, for example, Japanese Patent Application Laid-Open (*kokai*) No. 10-329031, Japanese Patent Application Laid-Open (*kokai*) No. 11-333705 (USP 6261162), or Japanese Patent Application Laid-Open (*kokai*) No. 2001-49243). This method is advantageous in that a relatively high polishing speed is achieved, by virtue of the fixed abrasive grains.

However, such a polishing method employing fixed abrasive grains involves problems, including generation of micro-scratches during the course of polishing, and generation of deep polishing marks attributed to falling of abrasive grains. Such scratches cause short circuit, thereby tending to lower the yield of the resultant device.

In order to attain production of a high-performance semiconductor device, precision of polishing of the surface of a substrate must be improved, and a substrate having neither scratches nor polishing marks must be provided. In

addition, there is required means for polishing a substrate without forming scratches thereon and for precisely polishing elements constituting the device, such as an interlayer insulating film and a circuit pattern.

In the field of cutting, high-efficiency, high-speed cutting has been performed by use of a cutting tool employing abrasive grains formed of material having high hardness. In recent years, from the viewpoint of environmental safety, dry cutting, which does not employ a cutting liquid, has been increasingly performed. In dry cutting, a cutting tool to be employed is desirably formed of a material exhibiting high thermal conductivity, since the temperature of the tool rises during the course of cutting. Therefore, advantageously, the cutting tool is formed of a material containing a large amount of, for example, diamond or cubic boron nitride, which exhibits particularly high thermal conductivity.

Particularly, cubic boron nitride is suitable for use as abrasive grains of a cutting tool for cutting a difficult-to-cut material; in particular, an iron-based difficult-to-cut material such as stainless steel, heat-resistant steel, high-hardness cast iron, sintered alloy, or hardened steel. A cutting tool material including a matrix (i.e., binder) formed of metal can be processed by means of wire-cut electrical discharge machining, which is performed at high efficiency and low cost. Meanwhile, a cutting tool material including a matrix formed of insulating ceramic material exhibits low electrical conductivity, and therefore, cutting

of the material for producing a cutting tool requires an expensive laser cutting machine. In the case of a cutting tool material, desirably, electrical conductivity is imparted to the material such that the material can be processed by use of an inexpensive, high-efficiency wire-cut electrical discharge machine.

Disclosure of the Invention

The present inventors have performed studies, and as a result have invented an abrasive composite material, a grinding wheel comprising the composite material, a grinding material comprising the composite material, a polishing material comprising the composite material, and a cutting tool material comprising the composite material, as described below. In addition, the present inventors have invented a method for processing an electronic part, and a method for processing silicon, the methods employing the grinding wheel, grinding material, or polishing material.

The abrasive composite material of the present invention contains carbon fiber, and when employed for grinding or polishing, exhibits excellent tribological characteristics, elasticity, electrical conductivity, thermal conductivity, and corrosion resistance. Therefore, when the abrasive composite material is employed, falling of abrasive grains is suppressed, friction resistance is reduced, non-uniform polishing is prevented, a polished surface is highly planarized, and high-precision grinding or polishing can be

attained. When the abrasive composite material of the present invention is employed to prepare a cutting tool material, the resultant cutting tool material exhibits improved electrical conductivity and thermal conductivity, realizes high-speed, high-efficiency cutting, and enables wire-cut electrical discharge machining to be performed. Therefore, inexpensive and efficient tool processing can be performed.

No particular limitations are imposed on the abrasive grains or matrix employed in the abrasive composite material of the present invention, and the abrasive grains or matrix can be formed of a conventionally known material. When the abrasive composite material is employed in the semiconductor field, the abrasive grains are preferably formed of at least one species selected from among cerium oxide, silicon oxide, and aluminum oxide. When the abrasive composite material is employed in a material of a tool for cutting an iron-based difficult-to-cut material, the abrasive grains are preferably formed of high-pressure phase boron nitride, particularly preferably cubic boron nitride. When the abrasive composite material is employed in a cutting tool material, the matrix is preferably formed of an oxide, nitride, or boride of aluminum.

When the processing method of the present invention is employed for grinding or polishing of silicon or a variety of electronic parts, falling of abrasive grains is suppressed, friction resistance is reduced, non-uniform polishing is

prevented, a polished surface is highly planarized, and high-precision grinding or polishing can be attained.

Accordingly, the present invention provides the following.

(1) An abrasive composite material comprising a matrix, abrasive grains, and carbon fiber having a multi-layer structure, each fiber filament of the carbon fiber having an outer diameter of 2 to 500 nm and an aspect ratio of 5 to 15,000, and including a hollow space extending along its center axis.

(2) An abrasive composite material according to (1) above, wherein the carbon fiber has a BET specific surface area of at least 4 m²/g.

(3) An abrasive composite material according to (1) above, wherein the carbon fiber has, at a carbon (002) plane, an interlayer distance (d₀₀₂) of 0.345 nm or less as measured by means of X-ray diffractometry.

(4) An abrasive composite material according to (1) above, wherein the ratio of the peak height (Id) of the band at 1,341 to 1,349 cm⁻¹ in a Raman scattering spectrum of the carbon fiber to the peak height (Ig) of the band at 1,570 to 1,578 cm⁻¹ in the spectrum; i.e., Id/Ig, is 1.5 or less.

(5) An abrasive composite material according to (1) above, wherein the carbon fiber contains branched vapor grown carbon fiber.

(6) An abrasive composite material according to (1) above, wherein boron is contained, in an amount of 0.01 to 5

mass%, in the interior of crystals constituting the carbon fiber.

(7) An abrasive composite material according to (1) above, wherein the amount of the carbon fiber is 2 to 40 vol.% with respect to the abrasive composite material.

(8) An abrasive composite material according to (1) above, wherein the abrasive grains are formed of at least one material selected from among cerium oxide, silicon oxide, silicon carbide, boron carbide, boron nitride, zirconium oxide, diamond, and sapphire.

(9) An abrasive composite material according to (1) above, wherein the matrix is formed of at least one material selected from among a resin, a metal, and a ceramic material.

(10) An abrasive composite material according to (9) above, wherein the resin contains at least one species selected from among a phenolic resin, a melamine resin, a polyurethane resin, an epoxy resin, a urea resin, an unsaturated polyester resin, a silicone resin, a polyimide resin, an epoxy resin, a cyanate ester resin, and a benzoxazine resin.

(11) A grinding wheel formed through molding of an abrasive composite material as recited in (1) above.

(12) A grinding material comprising an abrasive composite material as recited in (1) above.

(13) A polishing material comprising an abrasive composite material as recited in (1) above.

(14) A cutting tool material comprising an abrasive

composite material as recited in (1) above.

(15) A cutting tool material according to (14) above, wherein the matrix contains the carbon fiber in an amount of 20 to 45 vol.%.

(16) A wire-cut electrical discharge machining material comprising a cutting tool material as recited in (14) above.

(17) A wire-cut electrical discharge machining method employing a cutting tool material as recited in (14) above.

(18) A method for producing a cutting tool, which employs a wire-cut electrical discharge machining method as recited in (17) above.

(19) A method for producing an electronic part, which method comprises a step of grinding at least one species selected from among a semiconductor, an interlayer insulating film, and a wiring material by use of an abrasive composite material as recited in (1) above.

(20) A method for producing an electronic part, which method comprises a step of polishing at least one species selected from among a semiconductor, an interlayer insulating film, and a wiring material by use of an abrasive composite material as recited in (1) above.

(21) A method for producing an electronic part according to (19) or (20) above, wherein the semiconductor is at least one species selected from among polycrystalline silicon, single-crystal silicon, and amorphous silicon.

Modes for Carrying Out the Invention

The present invention will next be described in detail.

The abrasive composite material of the present invention contains a matrix (e.g., substrate, fabric, or powder), abrasive grains, and carbon fiber, wherein the abrasive grains and carbon powder are fixed onto the matrix. The abrasive composite material can be formed into, for example, a grinding wheel or a cutting tool material through molding of a mixture of the matrix, which also serves as a binder, the abrasive grains, and the carbon fiber; a polishing blade by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of a metallic or ceramic substrate serving as the matrix; or a polishing pad by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of the matrix formed of non-woven fabric.

As used herein, the term "grinding" refers to a process for removing a member, the process including cutting; the term "polishing" refers to a process for reducing irregularities on the surface of a member, thereby smoothing the member surface; and the term "cutting" refers to a process for cutting the surface of a member more deeply. As used herein, the terms "grinding material," "polishing material," and "cutting material" refer to materials employed for the aforementioned respective processes. Specific examples of the grinding material, polishing material, and cutting material include a grinding wheel, a polishing wheel, a grinding blade, a polishing pad, a dresser, a cutting tool,

a throw-away tip, and a drill.

(Abrasive grains)

No particular limitations are imposed on the type of abrasive grains employed in the present invention, and, in accordance with the type of a target workpiece, the abrasive grains may be selected from among conventionally known substances, for example, cerium oxide, silicon oxide, aluminum oxide, titanium oxide, zirconium oxide, silicon carbide, tungsten carbide, boron carbide, boron nitride, diamond, sapphire, and organic fine particles. When the abrasive composite material is employed in the semiconductor field, the abrasive grains are particularly preferably formed of at least one species selected from among cerium oxide, silicon oxide, and aluminum oxide. When the abrasive composite material is employed in a material of a tool for cutting an iron-based difficult-to-cut material, the abrasive grains are preferably formed of high-pressure phase boron nitride, particularly preferably cubic boron nitride.

In the case where the abrasive composite material is employed in a polishing material or a grinding material, the size of the abrasive grains employed in the present invention varies within a range of about 0.1 to about 100 μm , in accordance with the degree of surface finishing of a workpiece. Preferably, the abrasive grains have a size of about 0.3 to about 50 μm . When the grain size is about 0.1 μm or less, protrusions of the abrasive grains becomes small,

and the polishing speed is considerably reduced, whereas when the grain size is about 100 μm or more, the polishing speed increases, but the number of polishing marks on the surface of the resultant workpiece increases, the depth of the marks increases, and the surface roughness of the workpiece increases. In the case where the abrasive composite material is employed in a cutting material, the size of the abrasive grains is preferably about 0.05 to about 30 μm . When the grain size is about 0.05 μm or less, the amount of impurities on the surface of the composite material increases, leading to deterioration of sinterability, whereas when the grain size is about 30 μm or more, the structure of the composite material fails to be densified, resulting in reduction of strength.

When the abrasive composite material is formed into a grinding wheel, the amount of the abrasive grains added to the composite material is preferably about 3 to about 30 vol.%, more preferably about 5 to about 20 vol.%. When the amount of the abrasive grains is about 3 vol.% or less, the polishing speed decreases, sufficient planarization fails to be attained within a short period of time, whereas when the amount of the abrasive grains is about 30 vol.% or more, adhesion of a resin to the abrasive grains is lowered, and falling of the abrasive grains considerably occurs, resulting in an increase in the number of polishing marks.

When the abrasive grains are fixed onto the surface of the matrix, preferably, the ratio by volume of the abrasive

grains to the carbon fiber is regulated to about 1:0.5 to about 1:1.

When the abrasive composite material is employed in a cutting tool, generally, the abrasive grains are added to the composite material in an amount of about 40 to about 90 vol.%. However, from the viewpoint of enhancement of wear resistance and thermal conductivity of the composite material, the amount of the abrasive grains is preferably about 65 to about 90 vol.%. In the case where the amount of the abrasive grains is less than about 65%, characteristic features of the matrix are strongly reflected on the composite material, and thermal conductivity is lowered or hardness decreases, leading to deterioration of wear resistance. In contrast, in the case where the amount of the abrasive grains exceeds about 90 vol.%, when the abrasive grains have relatively high rigidity, the abrasive grains encounter difficulty in being uniformly mixed with the matrix.

(Matrix)

Examples of the matrix employed in the present invention include resins such as plastic and rubber; ceramic materials such as cement, glass, alumina, and aluminum nitride; and metals such as pure metals and alloys. Such a matrix may serve as a bond. The means for fixing the abrasive grains or carbon fiber onto the matrix may be any type of bond, such as resinoid bond, metal bond, vitrified bond, and electroplated bond. When a crystalline matrix is

employed, the carbon fiber can be inserted between crystal grains of the matrix through sintering which occurs between the matrix and the abrasive grains, between the matrix grains, or between the abrasive grains.

No particular limitations are imposed on the resin employed in the present invention, and a known resin may be employed. Examples of the resin which may be employed include thermosetting resins such as polyamide, polyether, polyester, polyimide, polysulfone, epoxy resin, unsaturated polyester, and phenolic resin; and thermoplastic resins such as nylon, polyethylene, polycarbonate, and polyarylate. Such a resin may be employed in combination with a foaming agent. If desired, there may be employed a foam regulating agent, an additive for regulating dispersion, humidity, or wettability of the abrasive grains, or a coupling agent for regulating the strength of bonding between the resin and the abrasive grains.

In the case where a resin is employed as the matrix, the resin, the abrasive grains, and the carbon fiber may be mixed together, and the resultant mixture may be subjected to compression molding, thereby forming a grinding wheel. Alternatively, the abrasive grains and the carbon fiber may be fixed, by use of a bond, onto the surface of a substrate or non-woven fabric formed of the resin serving as the matrix.

In the case where the abrasive grains and the carbon fiber are fixed onto the surface of a metallic or ceramic matrix, metal bond can be employed. The metal bond may be

copper, tin, iron, nickel, cobalt, or an alloy of such a metal. Vitrified bond is a ceramic or glassy bond (inorganic bond) prepared through sintering at about 800 to about 1,000°C. Electroplated bond is means for fixing the abrasive grains through electroplating.

(Carbon fiber)

The carbon fiber employed in the present invention is preferably vapor grown carbon fiber. In general, vapor grown carbon fiber can be produced by thermally decomposing an organic compound by use of an organo-transition metallic compound.

Examples of the organic compound which may serve as a raw material of the vapor grown carbon fiber include toluene, benzene, naphthalene, ethylene, acetylene, ethane, gasses such as natural gas and carbon monoxide, and mixtures thereof. Of these, aromatic hydrocarbons such as toluene and benzene are preferred.

An organo-transition metallic compound contains a transition metal serving as a catalyst, and is an organic compound containing, as a transition metal, a metal belonging to Group IVa, Va, VIa, VIIa, or VIII of the periodic table. An organo-transition metallic compound such as ferrocene or nickelocene is preferred.

The vapor grown carbon fiber is produced through the following procedure: the aforementioned organic compound and organo-transition metallic compound are gasified, and mixed

with a reducing gas (e.g., hydrogen) which has been preliminarily heated to about 500 to about 1,300°C; and the resultant mixture is fed into a reaction furnace heated to about 800 to about 1,300°C, to thereby allow reaction to proceed.

In order to enhance adhesion of the vapor grown carbon fiber to the matrix, preferably, the carbon fiber is subjected to thermal treatment in an inert atmosphere at about 900 to about 1,300°C, to thereby remove organic substances (e.g., tar) deposited on the surface of the carbon fiber.

In order to further enhance adhesion of the vapor grown carbon fiber to the matrix, the carbon fiber may be subjected to thermal treatment in an oxidative atmosphere at about 300 to about 450°C, or may be activated by use of, for example, carbon dioxide gas or potassium hydroxide, to thereby increase the area of a portion of the carbon fiber that adheres to the matrix.

The surface area of the vapor grown carbon fiber can be increased by means of dry milling employing, for example, a vibration mill or a jet mill, or by means of wet milling employing, for example, a bead mill.

In order to enhance affinity of the vapor grown carbon fiber to the matrix, the carbon fiber surface or the entirety of the carbon fiber may be subjected to, for example, fluorination or oxidation.

In order to improve characteristics (e.g., electrical

conductivity and thermal conductivity) of the vapor grown carbon fiber, the carbon fiber may be subjected to thermal treatment in an inert atmosphere at about 2,000 to about 3,500°C, to thereby enhance crystallinity thereof. In order to further enhance crystallinity and electrical conductivity of the vapor grown carbon fiber, the carbon fiber may be mixed with a boron compound such as boron carbide (B₄C), boron oxide (B₂O₃), elemental boron, boric acid (H₃BO₃), or a borate, and the resultant mixture may be subjected to thermal treatment in an inert atmosphere at about 2,000 to about 3,500°C, such that boron (B) is contained, in an amount of about 0.01 to about 5 mass%, in carbon crystals constituting the carbon fiber.

The vapor grown carbon fiber may be thermally treated by use of any furnace, so long as the furnace can maintain a target temperature of about 2,000°C or higher, preferably about 2,300°C or higher. The furnace may be a generally employed furnace, such as an Acheson furnace, a resistance furnace, or a high-frequency furnace. In some cases, there may be employed a method for heating powder or a molded product formed through compression of the vapor grown carbon fiber by applying electricity directly thereto.

Thermal treatment is carried out in a non-oxidative atmosphere, preferably in an atmosphere of one or more of rare gasses such as argon, helium, and neon. From the viewpoint of productivity, thermal treatment is preferably carried out within a short period of time. When carbon fiber

is heated over a long period of time, the carbon fiber is sintered to form aggregates, resulting in low production yield. Therefore, after the center of a molded product of the carbon fiber is heated to a target temperature, the molded product is not necessarily maintained at the temperature for more than one hour.

Each fiber filament of the vapor grown carbon fiber employed in the present invention preferably has an outer diameter of about 2 to about 500 nm. In order to cause the carbon fiber to sufficiently exhibit its characteristics, including tribological characteristics and electrical conductivity, the carbon fiber must be dispersed uniformly in the abrasive composite material. The outer diameter of the carbon fiber filament is more preferably about 10 to about 300 nm, much more preferably about 20 to about 200 nm. The greater the amount of the vapor grown carbon fiber distributed over the surface of the abrasive composite material, the more enhanced the tribological characteristics. When the outer diameter is less than about 5 nm, difficulty is encountered in uniformly dispersing the carbon fiber in the abrasive composite material, and friction resistance becomes non-uniform in the composite material, which causes non-uniform polishing. In contrast, when the outer diameter exceeds about 500 nm, a large amount of the carbon fiber must be added to the abrasive composite material in order to impart intended electrical conductivity and thermal conductivity to the composite material. As a result, the

mechanical strength of the abrasive composite material is lowered, and polishing marks attributed to falling of the abrasive grains or carbon fiber tend to be formed during the course of polishing.

Each fiber filament of the vapor grown carbon fiber employed in the present invention preferably has an aspect ratio of about 5 to about 15,000. In order to facilitate uniform dispersion of the carbon fiber in the abrasive composite material, more preferably, the aspect ratio of the carbon fiber filament is regulated to about 10 to about 100.

When the aspect ratio is less than about 5, the carbon fiber loses its characteristic feature in terms of fibrous form, and the carbon fiber fails to impart intended electrical conductivity and thermal conductivity to the abrasive composite material. In contrast, when the aspect ratio exceeds about 15,000, fiber filaments of the carbon fiber are entangled with one another, and difficulty is encountered in uniformly dispersing the carbon fiber in the abrasive composite material. As a result, immediately after the composite material is molded into a grinding wheel, planarity of the surface of the grinding wheel is impaired, and friction resistance becomes non-uniform in the grinding wheel surface, which causes low planarity of a workpiece.

The carbon fiber employed in the present invention preferably has a BET specific surface area of about 4 m²/g or more.

When the BET specific surface area is less than about 4

m^2/g , the area of a portion of the carbon fiber that adheres to the matrix becomes small, and thus the carbon fiber is not sufficiently captured by the matrix, leading to falling of the carbon fiber from the abrasive composite material during the course of grinding or polishing, which causes generation of scratches or polishing marks.

The carbon fiber employed in the present invention preferably has, at a carbon (002) plane, an interlayer distance (d_{002}) of about 0.345 nm or less as measured by means of X-ray diffractometry.

When the (d_{002}) value exceeds about 0.345 nm, thermal conductivity and tribological characteristics are impaired, which reduces the ability to radiate heat generated during polishing, leading to problems, including polishing burn.

In the carbon fiber employed in the present invention, preferably, the ratio of the peak height (I_d) of the band at 1,341 to 1,349 cm^{-1} in a Raman scattering spectrum of the carbon fiber to the peak height (I_g) of the band at 1,570 to 1,578 cm^{-1} in the spectrum; i.e., I_d/I_g , is about 1.5 or less.

I_d of the Raman spectrum is the height of the peak of a broad band corresponding to an increase in disturbance of a carbon structure, and I_g is the height of the peak of a relatively sharp band corresponding to a complete graphite structure. In general, the peak intensity ratio is employed as an indicator for the degree of graphitization of a carbon material. In the case where the peak intensity ratio is represented by the peak height ratio, when the degree of

graphitization is higher, the peak height ratio becomes lower.

When the ratio I_d/I_g exceeds about 1.5; i.e., crystallinity of a graphene sheet is low, the carbon fiber exhibits lowered electrical conductivity and thermal conductivity. Therefore, in some cases, difficulty is encountered in imparting intended electrical conductivity and thermal conductivity to the abrasive composite material.

The carbon fiber employed in the present invention has a multi-layer structure, each fiber filament of the carbon fiber including a hollow space extending along its center axis. Since each fiber filament of the carbon fiber includes a hollow space, the carbon fiber exhibits enhanced elasticity, and therefore the abrasive composite material exhibits enhanced polishing efficiency and enables suppression of generation of polishing marks. In addition, since the carbon fiber has a multi-layer structure, the carbon fiber exhibits high lubricity, and the abrasive composite material enables suppression of generation of polishing marks. Such a carbon fiber structure (i.e., a multi-layer structure including a central hollow space) is specific to carbon fiber produced through the vapor phase process.

The carbon fiber employed in the present invention may contain branched vapor grown carbon fiber. In many cases, branched vapor grown carbon fiber has a small outer diameter, and each fiber filament of the carbon fiber has a structure in which a central hollow portion extends throughout the filament including a branched portion thereof. In the case

where branched vapor grown carbon fiber is added to the abrasive composite material, even when the amount of the carbon fiber is small, an electrically conductive or thermally conductive network can be efficiently formed in the composite material, as compared with the case where typical vapor grown carbon fiber is employed. That is, in the case where branched vapor grown carbon fiber is added to the abrasive composite material in the same amount as typical vapor grown carbon fiber, the resultant composite material exhibits further enhanced electrical conductivity, thermal conductivity, tribological characteristics, and elasticity.

In the carbon fiber employed in the present invention, preferably, boron is contained in crystals constituting the carbon fiber in an amount of about 0.01 to about 5 mass%.

When the carbon fiber contains boron, the crystal layered structure is developed, and thus electrical conductivity is enhanced. In addition, by virtue of enhancement of crystallinity and the effect of boron contained in crystal planes, corrosion resistance of the carbon fiber is improved, and surface charge distribution varies. Therefore, the carbon fiber exhibits improved wettability to the matrix and improved tribological characteristics. When the boron-containing vapor grown carbon fiber is added to the abrasive composite material, friction resistance during the course of polishing can be reduced, and generation of friction heat can be suppressed. Furthermore, since adhesion of the carbon fiber to the matrix

is improved, falling of the carbon fiber during the course of polishing can be suppressed.

The abrasive composite material of the present invention contains a matrix (e.g., substrate, fabric, or powder), abrasive grains, and carbon fiber, wherein the abrasive grains and carbon powder are fixed onto the matrix. The abrasive composite material can be formed into, for example, a grinding wheel or a cutting tool material through molding of a mixture of the matrix, which also serves as a binder, the abrasive grains, and the carbon fiber; a polishing blade by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of a metallic or ceramic substrate serving as the matrix; or a polishing pad by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of the matrix formed of non-woven fabric.

When the abrasive composite material is formed into a grinding wheel, the carbon fiber added to the composite material is preferably about 5 to about 40 vol.%, more preferably about 10 to about 30 vol.%. When the amount of the carbon fiber is about 5 vol.% or less, the carbon fiber fails to impart sufficient tribological characteristics, elasticity, electrical conductivity, thermal conductivity, and corrosion resistance to the abrasive composite material, and therefore, the composite material fails to provide a planar polished surface. In contrast, when the amount of the carbon fiber is about 40 vol.% or more, adhesion between the

carbon fiber and the matrix is impaired, and the mechanical strength of the abrasive composite material is lowered. As a result, the carbon fiber or abrasive grains fall from the abrasive composite material during the course of polishing, leading to lowering of the quality of the composite material and a workpiece.

When the abrasive composite material is formed into a cutting tool material, the amount of the carbon fiber added to the composite material is preferably about 2 to about 15 vol.%, more preferably about 2 to about 10 vol.%. When the amount of the carbon fiber is about 2 vol.% or less, the carbon fiber fails to impart sufficient electrical conductivity to the abrasive composite material, and wire-cut electrical discharge machining cannot be performed. In contrast, when the amount of the carbon fiber is about 15 vol.% or more, wear of the composite material increases during the course of cutting, and chipping tends to occur.

When the abrasive composite material is formed into a product by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of a substrate, or a product by fixing the abrasive grains and carbon fiber, by use of a binder, onto the surface of the matrix formed of, for example, non-woven fabric, the amount of the carbon fiber is preferably regulated such that the ratio by volume of the abrasive grains to the carbon fiber is about 1:0.5 to about 1:1.

The above-prepared abrasive composite material of the

present invention, which contains the carbon fiber, exhibits elasticity, and thus does not apply excess load to an object to be polished. Therefore, the composite material enables suppression of generation of polishing marks.

Planarization of a workpiece requires planarity of a grinding wheel and uniform distribution of pressure at the surface at which the grinding wheel is in contact with the workpiece. When carbon fiber having low bulk density and exhibiting high elasticity, in particular, vapor grown carbon fiber, is added to a grinding wheel, the elastic modulus of the grinding wheel is increased, uniform polishing pressure can be applied to a workpiece, and the surface of the workpiece can be uniformly planarized. Even when excess pressure is applied to the workpiece, by virtue of pressure reduction by deformation of the grinding wheel, the depth of polishing marks can be decreased, and the number of polishing marks can be reduced.

In addition, since the grinding wheel exhibits enhanced tribological characteristics, electrical conductivity, thermal conductivity, and corrosion resistance, effects caused by physical or chemical factors during the course of polishing can be reduced.

Particularly when a semiconductor is ground or polished by use of diamond abrasive grains, oxidation of the diamond abrasive grains caused by oxygen in air and friction heat can be suppressed, and the lifetime of the abrasive composite material can be lengthened.

Furthermore, during the course of polishing of a semiconductor wafer or during the course of dressing of a polishing pad, falling of the abrasive grains of the abrasive composite material can be suppressed.

When the abrasive composite material is employed for polishing of a semiconductor wafer, friction resistance between the semiconductor wafer and a portion of the composite material other than the abrasive grains can be reduced, non-uniform polishing of the semiconductor wafer (i.e., workpiece) can be prevented, the surface of the wafer can be highly planarized, and polishing burn can be suppressed through radiation of generated friction heat.

In addition, when the abrasive composite material is formed into a grinding wheel, the composite material can impart excellent mold releasability to the grinding wheel.

When a workpiece is polished by a grinding wheel, which comes into surface contact with the workpiece, planarity of the polishing surface of the grinding wheel affects planarity of the thus-polished workpiece. Therefore, when a grinding wheel is formed from the abrasive composite material, a critical point is to remove the thus-formed grinding wheel from a mold so as to strictly conform the shape of the mold. In order to improve mold releasability during forming of the grinding wheel, a mold release agent, etc. may be employed. However, when the carbon-fiber-containing abrasive composite material of the present invention is employed, the resultant grinding wheel exhibits tribological characteristics, and

thus exhibits excellent mold releasability. Therefore, when the grinding wheel is employed for grinding or polishing of a workpiece, friction resistance between the workpiece and a portion of the grinding wheel other than the abrasive grains can be reduced during the course of grinding or polishing.

In addition, the abrasive composite material can impart electrical conductivity to the grinding wheel. Therefore, the thickness of the grinding wheel after polishing can be electrically measured, which enables control operations, including exchange of the grinding wheel.

In the case of production of a product through continuous polishing, in general, the product is planarized while the polishing amount is controlled by the polishing time, and therefore, measuring the thickness of a grinding wheel which has been employed for polishing is important, but the thickness of the grinding wheel is difficult to measure by means of laser or light. However, in the case of the carbon-fiber-containing grinding wheel of the present invention, since the carbon fiber exhibits high electrical conductivity, electrical conductivity is imparted to the abrasive grains and the grinding wheel, and the thickness of the grinding wheel can be controlled by means of electrical resistance. When the grinding wheel is provided on a substrate exhibiting electrical conductivity, electrical conduction is established throughout the resultant product, and thus the position of the substrate can be detected through electrical conduction detection means. In addition,

when the position of the substrate is controlled through control means, the same polishing conditions can be reproduced at any time.

In order to suppress polishing burn or exhaustion of the abrasive grains caused by friction heat generated during the course of polishing, in general, a coolant such as water is supplied to the grinding wheel during polishing. However, when the carbon fiber is added to the grinding wheel, further enhanced heat radiation and cooling effects can be obtained, and thus exhaustion of the abrasive grains can be suppressed.

Having been described grinding or polishing of a workpiece by use of the abrasive composite material of the present invention, the composite material can be employed in a dresser for a polishing pad.

When a semiconductor wafer is polished by use of, for example, a slurry containing dispersed abrasive grains, a polishing pad is cleaned between a wafer polishing step and the subsequent wafer polishing step. When a semiconductor wafer is subjected to, for example, chemical mechanical polishing, in many cases, a polishing pad formed of polyurethane foam is employed. When the polishing pad is observed under an electron microscope after polishing of the wafer, abrasive grains or chips of the workpiece are found to be deposited into pores on the pad surface, or the pores are found to be clogged by, for example, the effect of an additive (etchant) contained in the slurry. The clogged pores cause a decrease in the polishing speed, and the

deposited abrasive grains cause an increase in the number of polishing marks. Therefore, after polishing of the wafer, the polishing pad must be subjected to dressing, thereby removing excess abrasive grains, and returning the clogged pores to their original state. Since the pad surface often exhibits acidity or alkalinity due to the presence of the etchant contained in the slurry, preferably, the surface of a dresser to be employed exhibits chemical stability. When carbon fiber is added to the dresser, the area of a portion of the dresser that comes into contact with an acid or an alkali can be reduced, thereby attaining chemical stability, and falling of abrasive grains can be suppressed.

Next will be described the method for processing (grinding or polishing) an electronic part by use of a grinding wheel, a grinding material, or a polishing material, which contains the abrasive composite material of the present invention.

A semiconductor integrated circuit will now be described as an example of an electronic part. In production of a semiconductor integrated circuit, an insulating layer is formed on the surface of a silicon wafer which has undergone mirror polishing, and a circuit pattern formed of a thin film of a metal (e.g., aluminum) is formed on the insulating layer. In recent years, in order to enhance performance of an integrated circuit, a multi-layer integrated circuit including a plurality of insulating layers and circuit patterns has been widely employed. In formation of a fine

circuit pattern, a circuit pattern is printed, through exposure, onto a photo-resist film formed on the surface of a conductive thin film, followed by etching. Therefore, when the surface onto which a circuit pattern is to be printed does not have planarity, a precise circuit pattern cannot be formed. In the case of production of such a multi-layer semiconductor integrated circuit, a silicon wafer must be subjected to mirror polishing, and an interlayer insulating film or a metallic thin film for formation of a circuit pattern must be subjected to high-precision polishing, thereby imparting planarity thereto.

The electronic part processing method of the present invention is applied to grinding (including cutting) or polishing of a semiconductor material such as a silicon wafer, or to polishing of an interlayer insulating film or a metallic thin film to be formed into a circuit pattern. In the electronic part processing method, when a grinding wheel, grinding material, or polishing material formed of the abrasive composite material of the present invention is employed, occurrence of non-uniform polishing such as dishing or thinning can be prevented, and there can be obtained a precisely processed surface having neither micro-scratches nor polishing marks and exhibiting high planarity.

Particularly, the grinding wheel of the present invention is useful for grinding or polishing of silicon, such as polycrystalline silicon, single-crystal silicon, or amorphous silicon.

Examples

The present invention will next be described in more detail by way of Examples, which should not be construed as limiting the invention thereto. In the below-described Examples, characteristics are measured by means of the following methods.

(1) BET specific surface area

BET specific surface area was calculated from a nitrogen adsorption isothermal curve at the liquid nitrogen temperature by use of NOVA 1200 (product of Quantachrome) by means of the BET method and the BJH method. The adsorption amount of nitrogen was measured at a relative pressure (P/P_0) of 0.01 to 1.0.

(2) Raman scattering spectrum

Raman scattering spectrum of carbon fiber was obtained under the following conditions: excitation light: argon (Ar) laser (wavelength: 514.5 nm), detector: CCD (charge coupled device), slit distance: 500 μm , exposure time: 60 seconds.

(3) Surface electrical resistance

Five points of the surface of a material which had undergone grinding by use of vitrified diamond grinding wheel #325/400 were subjected to measurement of electrical resistance by means of the four-terminal method, and the average of the thus-measured values was obtained.

(4) Wire-cut electrical discharge machine (WEDM)

ROBOCUT α -0C (product of Fanuc Ltd.)

(5) Cutting test

Tool form: SNGN120308

Workpiece: iron-based sintered alloy (HRC 45)

V: 150 m/min

f: 0.15 mm/rev

d: 0.5 mm

Cutting length: 1200 m

Wear amount: represented by flank wear $V_{B\max}$

(Example 1)

A phenolic resin was mixed with cerium oxide (average particle size: 0.5 μm) (10 vol.%), and vapor grown carbon fiber having a multi-layer structure including a central hollow space (average fiber diameter: 200 nm, aspect ratio: 100, BET specific surface area: 10 m^2/g , d_{002} : 0.339 nm, Id/Ig : 0.1) (30 vol.%). The resultant mixture was subjected to pressure molding for 15 minutes under the following conditions: mold temperature: 160°C, molding pressure: 980.6 kP, to thereby produce a grinding wheel having a diameter of 50 mm and a thickness of 10 mm. An insulating-film-coated silicon wafer was polished for three minutes by use of the grinding wheel, while water was supplied to the wafer and a load of 49 kP was applied to the grinding wheel. During the course of polishing, the silicon wafer and the grinding wheel were rotated in the same direction such that the relative velocity between them was 10 cm/sec. The polishing speed was obtained by measuring the thicknesses of the wafer before and

after polishing by use of an optical interference thickness meter. The surface roughness of the thus-polished wafer was measured by use of a stylus-type roughness meter. Specimens were observed under an optical microscope for polishing marks.

The polishing speed and the surface roughness were found to be sufficiently practical levels; i.e., 300 nm/min and 2.0 nm, respectively. Observation of the polished surface under an optical microscope revealed that no polishing mark was generated on the wafer surface.

(Example 2)

A phenolic resin was mixed with cerium oxide (average particle size: 0.5 μm) (10 vol.%), and vapor grown carbon fiber having a multi-layer structure including a central hollow space (average fiber diameter: 20 nm, aspect ratio: 100, BET specific surface area: 100 m^2/g , d_{002} : 0.341 nm, Id/Ig : 0.2) (30 vol.%). The resultant mixture was subjected to pressure molding for 15 minutes under the following conditions: mold temperature: 160°C, molding pressure: 980.6 kP, to thereby produce a grinding wheel having a diameter of 50 mm and a thickness of 10 mm. An insulating-film-coated silicon wafer was polished for three minutes by use of the grinding wheel, while water was supplied to the wafer and a load of 49 kP was applied to the grinding wheel. During the course of polishing, the silicon wafer and the grinding wheel were rotated in the same direction such that the relative velocity between them was 10 cm/sec. The polishing speed was obtained by measuring the thicknesses of the wafer before and

after polishing by use of an optical interference thickness meter. The surface roughness of the thus-polished wafer was measured by use of a stylus-type roughness meter. Specimens were observed under an optical microscope for polishing marks.

The polishing speed and the surface roughness were found to be sufficiently practical levels; i.e., 280 nm/min and 1.5 nm, respectively. Observation of the polished surface under an optical microscope revealed that no polishing mark was generated on the wafer surface.

(Comparative Example 1)

A phenolic resin was mixed with cerium oxide (average particle size: 0.5 μm) (10 vol.%), and the resultant mixture was subjected to pressure molding for 15 minutes under the following conditions: mold temperature: 160°C, molding pressure: 980.6 kP, to thereby produce a grinding wheel having a diameter of 50 mm and a thickness of 10 mm. An insulating-film-coated silicon wafer was polished for three minutes by use of the grinding wheel, while water was supplied to the wafer and a load of 49 kP was applied to the grinding wheel. During the course of polishing, the silicon wafer and the grinding wheel were rotated in the same direction such that the relative velocity between them was 10 cm/sec. The polishing speed was obtained by measuring the thicknesses of the wafer before and after polishing by use of an optical interference thickness meter. The surface roughness of the thus-polished wafer was measured by use of a stylus-type roughness meter. Specimens were observed under

an optical microscope for polishing marks.

The polishing speed was found to be a sufficient level; i.e., 400 nm/min, but the surface roughness was found to increase to 10.0 nm. Observation of the polished surface under an optical microscope revealed that polishing marks were generated on the wafer surface in an amount of about 13 marks/cm².

(Comparative Example 2)

A phenolic resin was mixed with cerium oxide (average particle size: 0.5 μm) (10 vol.%), and vapor grown carbon fiber having a multi-layer structure including a central hollow space (average fiber diameter: 20 nm, aspect ratio: 2, BET specific surface area: 130 m^2/g , d_{002} : 0.341 nm, Id/Ig : 0.2) (30 vol.%). The resultant mixture was subjected to pressure molding for 15 minutes under the following conditions: mold temperature: 160°C, molding pressure: 980.6 kP, to thereby produce a grinding wheel having a diameter of 50 mm and a thickness of 10 mm. An insulating-film-coated silicon wafer was polished for three minutes by use of the grinding wheel, while water was supplied to the wafer and a load of 49 kP was applied to the grinding wheel. During the course of polishing, the silicon wafer and the grinding wheel were rotated in the same direction such that the relative velocity between them was 10 cm/sec. The polishing speed was obtained by measuring the thicknesses of the wafer before and after polishing by use of an optical interference thickness meter. The surface roughness of the thus-polished wafer was

measured by use of a stylus-type roughness meter. Specimens were observed under an optical microscope for polishing marks.

The polishing speed was found to be a sufficient level; i.e., 370 nm/min, but the surface roughness was found to increase to 8.5 nm. Observation of the polished surface under an optical microscope revealed that polishing marks were generated on the wafer surface in an amount of about 10 marks/cm².

Table 1 shows the results of polishing performed in the Examples and Comparative Examples.

Table 1 shows the percent defective and tribological characteristics of the grinding wheels of Examples 1 and 2 and Comparative Example 1, the percent defective being evaluated when the grinding wheel was released from the mold.

As used herein, "the percent defective" is defined by the percentage of grinding wheels which were broken when released from the mold, or grinding wheels whose surface was partially exfoliated and deposited onto the mold.

Tribological characteristics of the grinding wheel were evaluated by means of the thrust-type friction test. Specifically, an insulating-film-coated silicon wafer was pressed onto the grinding wheel for 60 minutes under application of a load of 147 kP, while the grinding wheel was rotated at 20 cm/sec. The amount of wear of the grinding wheel was measured after the test, and the thus-measured value was employed as an indicator for evaluation of tribological characteristics.

Table 1

	Ex. 1	Ex. 2	Comp. Ex. 1	Comp. Ex. 2
Polishing speed (nm/min)	300	280	400	370
Surface roughness (nm)	2.0	1.5	0.0	8.5
Polishing marks (marks/cm ²)	0	0	13	10
Percent defective (%)	1	1	40	-
Wear amount of grinding wheel (mg)	30	25	560	-

As is clear from Table 1, in the case of the grinding wheel of the present invention, a sufficiently practical polishing speed is attained, surface roughness is small, and high-precision polishing is attained without generating polishing marks.

In contrast, in the case of Comparative Example 1, in which carbon fiber is not employed, polishing speed is high, but surface roughness is significant, and polishing marks are generated. Meanwhile, in the case of Comparative Example 2, in which carbon fiber having a small diameter and a low aspect ratio is employed, surface roughness is significant, and polishing marks are generated.

As is clear from Table 1, when carbon fiber is added to the grinding wheel, mold releasability of the grinding wheel is improved. The results of the friction test reveal that addition of carbon fiber to the grinding wheel improves tribological characteristics thereof, and exhibits the effect of reducing the amount of wear of the grinding wheel.

(Example 3)

Cubic boron nitride (average particle size: 3 μm) (85 mass%), aluminum powder (average particle size: 10 μm) (15

mass%), and vapor grown carbon fiber having a multi-layer structure including a central hollow space (average fiber diameter: 150 nm, aspect ratio: 67, BET specific surface area: 13 m²/g, d₀₀₂: 0.339 nm, I_d/I_g: 0.1) (30 mass% on the basis of the entirety of the aluminum powder) were wet-mixed in the presence of acetone for three hours by use of cemented tungsten carbide balls. After being dried, the resultant mixture was sintered at a temperature of 1,450°C and a pressure of 5.5 GPa for one hour, to thereby produce an abrasive composite material having a diameter of 30 mm and a thickness of 4 mm. The thickness of the composite material was regulated by use of a surface grinding machine and a diamond grinding wheel. The composite material was subjected to cutting by use of a wire-cut electrical discharge machine, and to finishing by use of a tool grinding machine, so as to attain a size of 12.7-mm-square × 3.2 ^tmm. The surface electrical resistance of the composite material was measured, and the composite material was subjected to cutting test in which the composite material was employed for cutting of a sintered alloy (hardness: HRC45).

(Example 4)

The procedure of Example 3 was repeated, except that the amounts of the cubic boron nitride and the aluminum powder were changed to 90 mass% and 10 mass%, respectively, and the vapor grown carbon fiber was added in an amount of 30 mass% on the basis of the entirety of the aluminum powder, to thereby produce a composite material. The surface electrical

resistance of the composite material was measured, and the composite material was subjected to the cutting test. The composite material was able to be cut by a wire-cut electrical discharge machine.

(Example 5)

The procedure of Example 3 was repeated, except that the amounts of the cubic boron nitride and the aluminum powder were changed to 95 mass% and 5 mass%, respectively, and the carbon fiber was added in an amount of 30 mass% on the basis of the entirety of the aluminum powder, to thereby produce a composite material. The surface electrical resistance of the composite material was measured, and the composite material was subjected to the cutting test.

(Example 6)

The procedure of Example 3 was repeated (the ratio by mass of the cubic boron nitride to the aluminum powder was regulated to 85 : 15), except that the carbon fiber was added in an amount of 25 mass% on the basis of the entirety of the aluminum powder, to thereby produce a composite material. The surface electrical resistance of the composite material was measured, and the composite material was subjected to the cutting test.

(Example 7)

The procedure of Example 3 was repeated, except that the ratio by mass of the cubic boron nitride to the aluminum powder was regulated to 90 : 10 as in the case of Example 4, and the carbon fiber was added in an amount of 50 mass% on

the basis of the entirety of the aluminum powder, to thereby produce a composite material. The surface electrical resistance of the composite material was measured, and the composite material was subjected to the cutting test.

(Referential Example 1)

The procedure of Example 3 was repeated (the ratio by mass of the cubic boron nitride to the aluminum powder was regulated to 85 : 15), except that the carbon fiber was added in an amount of 20 mass% on the basis of the entirety of the aluminum powder, to thereby produce a composite material. The surface electrical resistance of the composite material was measured, and the composite material was subjected to the cutting test. The composite material was not able to be cut by a wire-cut electrical discharge machine.

(Referential Example 2)

The procedure of Example 3 was repeated, except that the ratio by mass of the cubic boron nitride to the aluminum powder was regulated to 90 : 10 as in the case of Example 4, and the carbon fiber was added in an amount of 20 mass% on the basis of the entirety of the aluminum powder, to thereby produce a composite material. The surface electrical resistance of the composite material was measured, and the composite material was subjected to the cutting test. The composite material was not able to be cut by a wire-cut electrical discharge machine.

(Referential Example 3)

The procedure of Example 3 was repeated, except that

the ratio by mass of the cubic boron nitride to the aluminum powder was regulated to 95 : 5 as in the case of Example 5, and the carbon fiber was added in an amount of 20 mass% on the basis of the entirety of the aluminum powder, to thereby produce a composite material. The surface electrical resistance of the composite material was measured, and the composite material was subjected to the cutting test. The composite material was not able to be cut by a wire-cut electrical discharge machine.

(Referential Example 4)

The procedure of Example 3 was repeated, except that the ratio by mass of the cubic boron nitride to the aluminum powder was regulated to 95 : 5 as in the case of Example 5, and the carbon fiber was added in an amount of 100 mass% on the basis of the entirety of the aluminum powder, to thereby produce a composite material. The surface electrical resistance of the composite material was measured, and the composite material was subjected to the cutting test. The composite material was able to be cut by a wire-cut electrical discharge machine, but tool fracture occurred in the cutting test.

(Comparative Example 3)

A commercially available cubic boron nitride tool including an aluminum compound serving as a binder was subjected to measurement of surface electrical resistance, and the tool was subjected to the cutting test.

Table 2

	Abrasive grains	Matrix		Carbon fiber	Carbon fiber content of matrix
	cBN	AlN	AlB ₂		vol. %
	Amount in abrasive composite material (vol. %)				vol. %
Ex. 3	69	15	9	7	22.5
Ex. 4	79	10	6	5	23.8
Ex. 5	89	5	3	3	27.3
Ex. 6	70	15	9	6	20.0
Ex. 7	80	8	4	8	40.0
Ref. Ex. 1	71	15	9	5	17.2
Ref. Ex. 2	80	11	6	3	15.0
Ref. Ex. 3	90	5	3.5	1.5	15.0
Ref. Ex. 4	84	5	3	8	50.0
Comp. Ex. 3	86	9	5	0	0

	Electrical resistance of composite material	Cutting by WEDM	Cutting performance V _B wear
	Ω/square		mm
Ex. 3	1.8 × 10 ⁰	Yes	0.28
Ex. 4	2.8 × 10 ⁰	Yes	0.25
Ex. 5	2.4 × 10 ⁻¹	Yes	0.23
Ex. 6	8.5 × 10 ⁰	Yes	0.22
Ex. 7	5 × 10 ⁻²	Yes	0.29
Ref. Ex. 1	2.4 × 10 ³	No	0.26
Ref. Ex. 2	1.2 × 10 ⁴	No	0.22
Ref. Ex. 3	10 ⁵ or more	No	0.21
Ref. Ex. 4	2 × 10 ⁻²	Yes	0.42
Comp. Ex. 3	10 ⁷ or more	No	0.35

*WEDM: wire-cut electrical discharge machine (model: FANUC ROBOCUT α-OC)

*Cutting test: workpiece: iron-based sintered alloy (HRC45), V: 150 m/min, f: 0.15 mm/rev, d: 0.5 mm, cutting length: 1,200 m

*Electrical resistance: surface electrical resistance, measured by means of the four-terminal method

Industrial Applicability

Since the abrasive composite material of the present invention contains carbon fiber, when the composite material is employed in a grinding material, a polishing material, or a cutting material, the resultant material exhibits tribological characteristics, elasticity, electrical conductivity, thermal conductivity, and corrosion resistance. When such a grinding or polishing material is employed, effects caused by physical or chemical factors during the course of processing can be reduced. Therefore, friction resistance is reduced, non-uniform polishing is prevented, a polished surface is highly planarized, and high-precision grinding or polishing can be attained without generating scratches or polishing marks. In addition, falling of abrasive grains during the course of grinding or polishing can be suppressed, generation of polishing marks can be suppressed, burden on post-treatment of abrasive grains can be reduced, and a grinding material or polishing material having long lifetime can be provided.

Furthermore, when the abrasive composite material of the present invention is formed into a grinding wheel, the composite material can impart excellent mold releasability to the grinding wheel.

In addition, when the abrasive composite material is formed into a grinding wheel or a tool material, electrical conductivity is imparted to the grinding wheel or the tool material. Therefore, the thickness of the grinding wheel

after polishing can be electrically measured, which enables control operations, including exchange of the grinding wheel. Even when the amount of insulating abrasive grains contained in the tool material is high, the tool material can be subjected to cutting by use of a wire-cut electrical discharge machine; i.e., the tool material can be processed efficiently at low cost. Moreover, enhanced heat radiation and cooling effects can be obtained, and thus exhaustion of abrasive grains can be suppressed.

When the electronic part processing method of the present invention is employed, a semiconductor substrate, or an interlayer insulating film or circuit pattern constituting an electronic device can be processed at high precision and high efficiency. Particularly, the processing method exhibits its effects when employed for grinding or polishing of silicon, such as polycrystalline silicon, single-crystal silicon, or amorphous silicon. The abrasive composite material of the present invention can be employed in a dresser for a polishing pad.